## Physics 171

## Final Exam

Do the attached problems on the paper provided. Extra paper is available at the front of the room if you need more. Be sure to write your name and the problem number on any extra sheets you use!!

You may use your own pens, pencils, erasers, calculator and one $8 \frac{1}{2}$ " $\times 11$ " sheet of paper pre-prepared with any information you think you might need.
The exam will be graded on the basis of CLARITY of PRESENTATION of your reasoning, as well as correctness of the final answer. You must also show the units on numerical answers to obtain full credit.

Name
Signature
Please sign at the right if you would like to have your grade posted in a non-alphabetical list using social security number identifiers.

1. A particle of mass 4.6 kg follows the trajectory:

$$
\vec{r}(t)=\left(1 m / s^{3} t^{3}\right) \hat{x}+\left(5^{m} / s t\right) \hat{y}
$$

as shown in the figure. The points in the figure show the positions measured at equal time intervals of 1 s .

a) Find the expressions for the vector velocity, acceleration and force as a function of time, and draw the vectors indicating the directions of the velocity and force at points A and B on the diagram. Indicate the units on all numbers in your expression.
b) Find the angle between the direction of motion and the force at point A .
c) The force on the particle can also be expressed as a function of position as:

$$
F(x)=\left(27.6 N / m^{1 / 3}\right) x^{1 / 3}
$$

Assuming the force is conservative, find an expression for the potential energy of the particle as a function of $x$.
d) Write down three different equations that could be used to calculate the work in moving the particle from point A to point B , and solve one of them to obtain a numerical value.
2. An observer on earth sees a photon and an energetic particle and a second observer, all traveling in the positive x direction, pass by at $\mathrm{t}=0$. The energetic particle's speed is 0.750 c , and the second observer's speed is 0.500 c .
a) What values does the earth observer measure for the positions of the photon and the energetic particle at $\mathrm{t}=10.0 \mathrm{~ns}$ after they pass by?
b) What coordinates (position and time) does the second observer measure for each of the events in part a? (The "events" are the photon and the energetic particle each at the position calculated in (a) at time $\mathrm{t}=10 \mathrm{~ns}$ in the earth observer's frame.)
c) Now let's suppose that at $\mathrm{t}=10.0 \mathrm{~ns}$, the energetic particle broke apart into three pieces, one of which remained stationary (in the earth's frame) at the point of decomposition. The second observer came by a small time later and measured (simultaneously) the position of the earth and the remaining piece of the energetic particle. What distance does the second observer measure between the remaining piece and the earth? Explain the relationship between your answer to this question and your answer to part b.
3. A narrow rod has a mass of 5.50 kg and a length of 2.00 m . It is at rest on a frictionless surface. A point mass, $\mathrm{m}=2.40 \mathrm{~kg}$ traveling perpendicular to the stick with speed $v=0.334 \mathrm{~m} / \mathrm{s}$ hits it 0.350 m off center.
a) What is the position of the center of mass when the point mass hits the rod? (treat the rod as having no width)
b) What is the velocity of the center of mass of the rod plus mass.
c) What is the angular momentum of the point mass with respect to the center of mass just as it hits the rod? (treat the rod as having no width)
d) If the point mass sticks to the rod in the collision, what is the moment of inertia of the rod plus point mass with respect to an axis through the center of mass?
e) What is the position of the bottom end of the rod 1 s after the collision? (Hint: tell me the position of the system center of mass, and the angle of rotation of the rod with respect to the system center of mass.)

4. A small block of mass $m_{1}$ is sitting on top of a larger block of mass $m_{2}$. The static coefficient of friction between the blocks is $\mu_{\mathrm{S}}$ and the kinetic coefficient is $\mu_{\mathrm{k}}$. (As is always the case $\mu_{\mathrm{s}}>\mu_{\mathrm{k}}$.) The interaction between the large block and the floor is frictionless. A horizontal force Fo is applied to the large block.

a) When Fo is small, the two blocks slide together (with no slipping of $m_{1}$ with respect to $\mathrm{m}_{2}$ ). What is the acceleration of the system in this case?
b) When Fo is large, the small block $\mathrm{m}_{1}$ slides along the large block $\mathrm{m}_{2}$. What is the acceleration of each of the two blocks in this case?
c) What is the value of the force Fo where the behavior of the system changes from no slipping (as described in a) to slipping (as described in b) of the small block $\mathrm{m}_{1}$ with respect to the large block $\mathrm{m}_{2}$ ?
5. An monoatomic ideal gas is confined in a two-dimensional container (only x and y motion allowed) and equilibrated at a temperature of 350 K .
a) What is its internal energy? (Hint: how many translational degrees of freedom are there ?)
b) If the atomic mass of the atoms in the gas is $28.1 \mathrm{~g} / \mathrm{mole}$, what is the root mean square velocity of an atom?
c) The distribution of speeds of the atoms is found to obey the equation:

$$
N(v)=2 \pi A v e^{-m v^{2} / 2 k T}
$$

Find an expression for A in terms of the macroscopic parameters of the ideal gas.
6. A diatomic ideal gas is held in a box of volume $9 \mathrm{~m}^{3}$, at a temperature of 500 K and a pressure of 0.1 atm . The atoms in the molecules can rotate, but not vibrate at this temperature.
a) How much gas is in the box?
b) The gas is heated to 600 K without changing volume. How much heat was transferred to the gas?
c) Then the gas is slowly allowed to expand at constant temperature ( 600 K ) until it reaches its original pressure. What is the final volume of the gas? How much work is done by the gas during this expansion
d) Draw a pressure-volume diagram for the two step expansion of the gas described in parts b and c . On the same diagram, draw the pressure-volume line for a one step heat transfer from 500 K to 600 K at constant pressure. Explain the difference in the work available from the two processes.
7. A particle of mass $m$ is on a frictionless table. It is attached to a string that passes through a hole in the table. The particle rotates on the table around the hole with speed $v$ and radius R.
a) What tension must be exerted on the string to maintain the particle in uniform circular motion?
b) If one pulls down on the string until the mass moves inward to $1 / 4$ the original radius, what is the new speed of rotation? What is the new tension in the string? (Hint: what is conserved in this process?)
c) How much work had to be done to move the mass inward to the new radius?

